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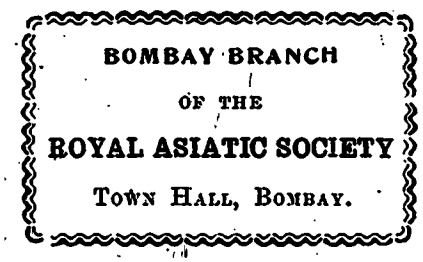

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RESEARCHES

ON THE

SOLAR SPECTRUM,

AND THE

SPECTRA OF THE CHEMICAL ELEMENTS.

BY

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TRANSLATED WITH THE AUTHOR'S SANCTION FROM THE TRANSACTIONS OF THE BERLIN ACADEMY FOR 1861.

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BY

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WITH THREE PLATES.

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TRANSLATOR'S PREFACE.

The general interest which the recent important discoveries in Optical Chemistry have excited in this country fully justifies the appearance of an English Translation of Professor Kirchhoff's Memoir on the Constitution of the Solar Spectrum and the Spectra of the Chemical Elements.

It is to Professors Bunsen and Kirchhoff that we chiefly owe the foundation of an entirely new branch of Chemical science, viz. the application of Spectrum-observations to Qualitative Analysis. They have shown, by an accurate examination of the Spectra of the metals, that bodies supposed to be of rare occurrence, are very widely diffused, and they have revealed the existence of metals which were previously unknown, thus pointing out the direction in which our knowledge of the composition of terrestrial matter may be almost indefinitely extended.

Professor Kirchhoff's discoveries of the exact coincidence of the bright lines formed in the Spectra of certain metals with the dark Solar lines, and of the power which luminous gases possess of absorbing light of the same degree of refrangibility as they emit, has opened another vast field for new inquiry concerning the composition of extra-terrestrial matter.

The Memoir by Professor Kirchhoff, of which a translation is now presented to the English scientific public, contains a description

of the methods of experiment adopted by him in the investigation of the Solar Spectrum and of the Spectra of the Elementary bodies, and an explanation of the results obtained, together with a theory respecting the constitution of the Sun's body.

The subject is divided under five heads, viz.:—

1. The Solar Spectrum.
2. The Spectra of the Chemical Elements.
3. The Reversal of the Spectra of coloured Flames.
4. The Chemical Constitution of the Solar Atmosphere.
5. The Physical Constitution of the Sun.

The original Memoir was printed in the Transactions of the Physical Section of the Berlin Academy for 1861, and is accompanied by two lithographic maps of the fixed lines in a portion of the Solar Spectrum, showing the coincidence of these with the bright lines of certain metallic Spectra. Impressions of the same maps, which are exact copies of Professor Kirchhoff's drawings, and masterpieces of lithographic art, have been secured for the English edition, and this will, therefore, resemble in every detail the German text.

The maps of the remaining portion of the Spectrum between the lines *A* and *G*, not represented in the two Plates accompanying the Memoir, will be published as soon as Professor Kirchhoff has completed the observations and the drawings.

H. E. R.

Owens College, Manchester,
February, 1862.

ON THE SOLAR SPECTRUM.

If a pure solar spectrum, obtained by a prism, be observed by means of a telescope of small magnifying power, an indistinct maze of fine lines and nebulous bands is seen between the more prominent lines which Fraunhofer has designated by separate letters. If several prisms and a higher magnifying power be employed, and if the apparatus be constructed with the requisite care, a number of groups of lines are seen which are so characteristic and can be so easily recognised, that they may, with propriety, be compared to the groups of stars by means of which the various constellations are distinguished. In Fraunhofer's original map of the solar spectrum[1] but very few of these groups can be recognised; and the same remark applies to the drawing on a much larger scale more recently published by Brewster and Gladstone[2]. I have endeavoured to produce a drawing of these groups of lines in the brightest portion of the solar spectrum, which shall represent the reality as faithfully and completely as possible. Plates I. and II. are lithographic copies of my own drawings[3].

The magnificent apparatus, which I have employed for the observations on the spectrum, was manufactured in the celebrated optical atelier of C. A. Steinheil of Munich. It is represented in Plate III. fig. 1.

[1] *Denkschriften der Münchener Academie* für 1814—1815.

[2] *Philosophical Transactions* for 1860, p. 149.

[3] My drawing is intended to include that portion of the spectrum contained between the lines *A* and *G*. I must, however, confine myself at present to the publication of a part only of this, as the remainder requires a revision, which I am unfortunately unable to undertake, owing to my eyes being weakened by the continual observations which the subject rendered necessary.

The telescope A is screwed on to a circular iron plate, having its surface turned plane; the eye-piece of this telescope is replaced by a metal plate containing an accurately made slit, formed of two knife-edges. The breadth of this slit can be regulated by a micrometer screw, and the slit itself can be brought into the focus of the achromatic object-glass by means of a rack-and-pinion motion. The focal length of this lens is 18 paris inches, and its diameter 18 paris lines. The telescope B, containing a similar object-glass, is fastened to a brass arm, which is moveable about the centre of the iron plate, and this motion can be given to it either with the hand or with a micrometer screw. Between the two object-glasses four flint-glass prisms are placed; each of these possesses circular refracting faces 18 paris lines in diameter; three of them have a refracting angle of 45°, the fourth one of 60°. Each of the prisms is cemented on to a small brass stand furnished with three set-screws. The telescope B has a double motion with respect to its brass arm; it can be moved about a horizontal axis, and can be drawn in and out in the direction of this axis, as is seen in the figure. The magnifying power of the telescope which I have used in my observations is about 40.

I have employed the following method for setting up the apparatus. The telescope B adjusted for viewing a very distant object, then placed in a line with the tube A, and the slit pushed in or out until it was plainly seen through the object-glass of A. The two tubes were next brought into such a position that their axes cut one another at right angles, and in the point of intersection was placed a plate of glass with plane and parallel surfaces, fastened on to a brass stand like the prisms. The set-screws of this stand were so altered, and the telescope B inclined in such a direction, that the image of the middle point of the slit always coincided with the point of intersection of the cross wires of the telescope B, whichever side of the plane plate of glass was turned towards the observer. The glass plate whose surfaces were thus placed at right angles to the surface of the iron plate, was then exchanged for one of

the prisms, and the set-screws of its stand were altered until the same coincidence appeared, when first one and then the other of its refracting surfaces served as the reflector. The refracting edge of the one prism being thus placed at right angles to the surface of the iron plate, the positions of the other prisms were similarly arranged. A heliostat, furnished with clockwork motion, was then placed so that the sun's rays fell into the observing room, and the iron plate was moved until the beam which passed through the slit illuminated the central portion of the object-glass of the tube *A*. The prisms and the telescope *B* were then arranged so that the spectrum was plainly seen; and the prisms were turned into the position of minimum deviation for the rays which had to be observed, and so placed that the rays which passed through the centre of the object-glass of the tube *A* also passed through the middle of the prisms. The telescope *B* was, lastly, moved in a direction parallel to itself, until those of the rays under examination which passed through the middle of the object-glass of *A*, likewise fell upon the middle of the object-glass of *B*. This condition, which was found to be essential to the purity of the spectrum, was secured by means of two caps, each of which contained a narrow vertical slit, and could be placed before each object-glass. When the telescope *B* was wrongly placed, the whole field appeared dark; by gradually moving the tube a band of light was seen which could be brought into the centre of the field. When the caps were taken off the object-glasses, the slit made of the right degree of breadth, and the eye-piece of *B* slightly altered, the spectrum appeared with a degree of distinctness which I believe had never before been attained.

In order to measure the distances between the several lines, I made use of a circular divided scale, attached to the head of the micrometer screw, by means of which the telescope *B* is moved. The eye-piece was placed so that the cross wires made angles of 45° with the dark lines; the point of intersection was brought by means of the micrometer screw to coincide with each of these lines, the divisions read off, and the estimation of the breadth and darkness of the line noted.

After these observations the drawings of the lines were prepared. For the purpose of drawing the lines I employed a kind of dividing instrument, consisting of the scale of a cathetometer placed in a horizontal position, on to the slide of which I had a tracer fitted such as is used in ordinary dividing machines. In the place of the graver a common drawing-pen was fastened, and to the screw of this a circle was attached, marked so as to correspond to the breadth of the lines to be drawn. These lines were also arranged according to their degree of blackness. First the darkest lines were drawn with thick black indian-ink; the ink was then diluted to a certain extent, and the lines of the next shade drawn, and so on to the lightest series. As soon as a portion of the spectrum had been drawn in this manner, it was compared with the actual spectrum, the mistakes in breadth and darkness of the lines, as well as in their position, corrected by fresh estimations, and the drawing made anew. A second comparison and another drawing were then made, and this process repeated until all the groups of lines appeared to be truthfully represented.

Above the drawing of the spectrum I have placed a scale divided into millimetres, and having an arbitrary commencement. This is, in the first place, useful for the purpose of obtaining an easy means of nomenclature for the lines. I propose that each of the lines should be called by the number placed above it on the scale. Thus, for instance, I designate the two lines, which Fraunhofer called *D*, by the numbers 1002·8 and 1006·8; Fraunhofer's line *E* consists of the two lines 1522·7 and 1523·7; the three lines 1633·4, 1648·3, and 1655·0 are in Fraunhofer's map called *b*.[1] By means of this scale we are likewise enabled

[1] The Plates I. and II. are printed with ink of six different tints from six different stones. Owing to mechanical difficulties it was found to be impossible to effect a complete coincidence between the separate copies and the original. In order to enable the reader to judge of the slight errors introduced by the lithography and the printing, I give, in a Supplement, the series of readings of the scale which in the original drawing correspond to the middle of the various lines. For the sake of easy comparison I have added to this table the values of darkness and of breadth of the lines. The degrees of darkness

to specify with a greater degree of accuracy the positions in the spectrum where no dark lines occur. A relation between the numbers on the scale corresponding to the individual lines and the refractive indices of my prisms for these lines does not exist, because the prisms were sometimes placed more exactly than at other times at the angle of minimum deviation for the particular rays.

Brewster has made the remarkable discovery that new dark lines appear in the solar spectrum when the sun approaches the horizon; these lines undoubtedly have their origin in our own atmosphere. In my apparatus I have often observed groups of such lines, especially in the neighbourhood of the lines *D*, appear with extraordinary beauty; but I have not placed them in my drawing, because it was intended to be a representation of what is seen in the solar spectrum when the sun is at a considerable altitude.

When the sun stood high in the heavens, I have also noticed traces of lines and nebulous bands in the most widely different portions of the spectrum, but I have not attempted to reproduce these in the drawing. I do not, however, doubt that by the employment of a larger number of prisms these might be resolved into distinct groups of lines. From the results obtainable with my instrument it is evident that the art of the optician is so far advanced that double or treble the number of prisms which I used may be employed without impairing the distinctness of the lines. The deviation would then become more than 180°, but this circumstance would not matter if the prisms were arranged in a spiral. The resolution of these nebular bands appears to me to possess an interest similar to that of the resolution of the celestial nebulæ, and the investigation of the solar spectrum to be of no less importance than the examination of the heavens themselves.

are given by the numbers 1, 2, 3, 4, 5, 6, the number 1 representing the least dark, and number 6 the darkest; whilst the difference in breadth of the lines is expressed by the letters *a*, *b*, *c*, *d*, *e*, *f*, *g*, *a* signifying the smallest, and *g* the greatest breadth.

ON THE SPECTRA OF THE CHEMICAL ELEMENTS.

The colours which the salts of certain metals impart to the blowpipe flame have long been used by chemists as indications of the presence of these metals; thus a yellow flame is caused by the salts of sodium, a violet flame is produced by potassium salts, lithium and strontium salts give a red flame, and salts of barium tinge the flame green. The value of these coloured flames as a means of detecting the metals was however diminished when several of these metals were present at once, because the flame produced by one metal obscured that given by another. Cartmell[1], at Bunsen's suggestion, showed that this evil might in many cases be remedied by the use of coloured glasses or liquids, through which the flame is observed, and previous to this Bunsen had simplified the method by using the slightly luminous flame of his gas-lamp in place of the blowpipe flame. The substitution of a prism for the coloured glasses or liquids, in decomposing the mixed colours in the flame, easily followed, especially as the prism had already been often employed in the examination of the spectra of various flames. Fraunhofer observed certain bright lines in the spectrum of the flame of a candle; Brewster and W. A. Miller had noted others, and Swan[2] had with great care measured the position of the bright lines occurring in the spectrum of the inner cone of a Bunsen's gas-flame, and had also observed that the same lines are found in the spectra of the flames of several other hydrocarbons.

W. A. Miller carried out his experiments by dissolving the salt under examination in alcohol, and analyzing the flame of the alcohol by means of a prism: drawings of the spectra which he thus obtained accom-

[1] *London, Edinburgh and Dublin Philosophical Magazine*, 4th Series, Vol. XVI. p. 328, Nov. 1858.

[2] *Transactions of the Royal Society of Edinburgh*, Vol. XXI. Part III. Poggendorff's *Annalen*, Bd. 100.

pany his paper[1]. Bunsen and I, in a research which we made together[2], replaced Miller's alcohol-flame by that of a Bunsen's gas-lamp, which is less luminous and possesses a higher temperature. Into the mantle of this flame we brought various salts by means of a fine platinum wire, and, amongst others, those which Miller had examined; and we observed the spectrum of the luminous vapour which ascended from the bead of salt. The phenomena which thus presented themselves differed essentially from those represented by Miller; they belong to the most brilliant optical phenomena which can be observed, and in comparison with the spectra drawn by Miller, they were so simple that their characteristic points could at once be seized. The reason of this was that we only saw the spectrum corresponding to the salt employed, and this in its greatest brilliancy, whereas, in Miller's experiment, the characteristic appearance of the spectrum was to a great extent concealed by the light of the burning alcohol.

We easily convinced ourselves that the most different salts of the same metal, if they are volatile, produce the same bright lines in the spectrum, but with different degrees of brilliancy; and that a mixture of salts of different metals gives a spectrum similar to that which would be produced by a superposition of the several spectra of the individual metals. We were able to found upon the occurrence of these bright lines a method of qualitative chemical analysis, the importance of which is evidenced by the numerous series of discoveries to which the method has already given rise.

After we had become acquainted with the characteristic lines of the several metals as seen by help of Bunsen's gas-flame, we were able to recognize these same lines either in the spectra of other flames less well adapted for the purpose, into which a volatile salt of the metal was brought, or in the spectrum of an electric spark from electrodes composed of the metal, or moistened with a solution of a volatile salt of the metal in question.

[1] *Philosophical Magazine*, 3rd Series, Vol. XXVII. p. 81, August 1845. Poggendorff's *Annalen*, Bd. 69.

[2] Poggendorff's *Annalen*, Bd. 110. *Philosophical Magazine*, 4th Series, Vol. XX. p. 89.

The dark lines of the solar spectrum afford invaluable assistance in determining the position of the bright lines of the various elementary bodies. In order to make use of these dark lines I have fixed on to the upper half of the slit in the apparatus above described two small rectangular glass prisms, so arranged that whilst direct sunlight can enter the lower half of the slit, the rays from an artificial source of light placed at one side can reach the large prisms after twice suffering total reflection. The small prisms were placed upon each other so that their hypothenuse faces were parallel, and after the one had been turned round the axis perpendicular to the surfaces in contact, through an angle of about 15°, they were cemented together with rosin, and in this position fastened before the slit, as represented in Plate III. Fig. 2. In this way, whilst in the upper half of the field of the (astronomical) telescope the solar spectrum is seen, in the lower half, but in immediate contact with the other, the spectrum of the artificial source of light becomes apparent, and the positions of the bright lines in the latter spectrum can be accurately compared with those of the dark lines in the solar spectrum. In order to obtain the spectra of the metals, I have almost invariably employed the electric spark, chiefly owing to its great luminous intensity.

The spectrum of the electric spark was first examined by Fraunhofer, who noticed in it several bright lines. Wheatstone discovered that the spectrum differs according to the nature of the electrodes. Masson drew the spectra of several metals. Ångström found that the bright lines thus produced must be divided into two series, one of which is dependent on the nature of the gas through which the spark passes, and the other on the nature of the metal of which the electrodes are composed. Van der Willigen rendered the experiments on the spectra of the electric spark much easier by replacing the electrical machine, which had been employed by the former experimenters, by a Ruhmkorff's induction coil; and he first observed that when the electrodes were moistened with the solution of certain salts, lines which had not been seen before became visible. Plücker investigated the spectra of the electric light in Geiss-

ler's vacuum-tubes when these contained traces of various gases, and he measured the position of the bright lines observed in these spectra. Foucault experimented upon the spectra of the electric arc from poles of carbon, and of various metals, and remarked the great brilliancy exhibited by many of the lines thus produced.

In my experiments I have produced the electric spark according to the method proposed by Van der Willigen. For this purpose I used one of Ruhmkorff's induction-coils, which, by means of a moderately powerful battery, gave sparks 0·3 metre in length. The battery which I employed consisted of three or four carbon-zinc elements of large surface, such as M. Ruhmkorff is in the habit of using for his large coils. The ends of the induction-wires were placed in contact with the coatings of a Leyden jar, the area of each of the surfaces of which was about 0·2 square metre; from the jar broad bands of copper led to the electrodes between which the sparks were to pass. The length of spark which I chose was 3 millimetres. The electrodes consisted in most instances of wires from 1 to 2 millimetres in diameter; sometimes pieces of metal of irregular form fastened on to the copper-wires were employed, and occasionally the metal under examination was not used in the uncombined state but in the form of the chloride, the solution of which was placed on an electrode consisting of some other metal whose spectrum was well known.

The light of the electric spark, after being twice totally reflected from the surfaces of the small prisms fastened upon the slit, had to pass in a direction parallel to the axis of the tube *A*. In order to find the right position of the electrodes, I placed the flame of a candle before the eye-piece of telescope *B* in the direction of its axis, and setting the eye in a particular position in front of the slit, I saw, through the small prism, one half of the slit illuminated with the colour upon which the telescope was fixed. I then found the position in which the half of the slit appeared brightest, and placed the electrodes so that the line joining their extremities occupied this position.

In comparing the bright lines of the electric spectra with the dark lines of the solar spectrum, I used the slit as narrow as I had employed it for the examination of the solar spectrum alone. Notwithstanding the brilliance of the electric spark most of the lines seen in the spectrum were not very bright, and in order to render these more distinct I diminished the intensity of the solar spectrum by allowing the sunlight before it reached the slit to pass through coloured glasses. Plates I. and II. give the representation of the result of these observations. I have endeavoured to reproduce the variation in the intensity of the several bright lines, as far as is possible in a drawing, by using lines of three different degrees of thickness. Most of the bright lines appeared considerably broader than they would have done if their light had in the strictest sense been homogeneous, but I have not represented this in the drawing, except in some specially prominent cases in which the lines appeared as broad bands. An example of such bands is seen in the broad green lines which occur in the zinc spectrum, one of which has the limits 1996 and 2000, and the other the limits 2014 and 2018. The horizontal line joining the lower ends of the vertical lines, which represent the bright bands, is intended to connect these bands together, and to shew that the chemical symbol *Zn* (zinc) applies to both the vertical lines.

The bright lines, produced by the incandescence of the atmospheric air, were scarcely visible owing to the small distance between the electrodes[1], and to the slight breadth of the slit. Of these atmospheric lines I have only given a representation of one group in the yellow, and one in the green, although I have observed many more. Indeed with respect to the lines of the spectra of the metals, this drawing does not make pretensions to completeness, as I have only endeavoured here to depict those lines which are the most prominent.

If we compare the spectra of the different metals with each other, several of the bright lines appear to coincide. This is especially notice-

[1] Compare Van der Willigen, Poggendorff's *Annalen*, Bd. 106, p. 615.

able in the case of an iron and magnesium line at 1655·6, and with an iron line and calcium line at 1522·7. It seems to me to be a question of great interest to determine, whether these and other similar coincidences are real or only apparent; whether the lines in question actually fall one upon the other, or whether they lie very close together. I believe that my method of observation does not possess the requisite accuracy for the purpose of answering this question with any degree of probability, and I think that a larger number of prisms and an increased intensity of the light will prove necessary. This might probably be accomplished by substituting the continuous current of a powerful battery for the induction-spark of a Ruhmkorff's coil.

I close this section with the following remarks. The position of the bright lines, or, to speak more precisely, the maxima of light in the spectrum of an incandescent vapour, is not dependent upon the temperature, upon the presence of other vapours, or upon any other conditions except the chemical constitution of the vapour. Of the validity of this conclusion Bunsen and I have assured ourselves by experiments made for that special object, and I have confirmed it by many observations made with the extraordinarily delicate instrument just described. The appearance of the spectrum of the same vapour may, nevertheless, be very different under different circumstances. Even the alteration of the mass of the incandescent gas is sufficient to effect a change in the character of the spectrum. If the thickness of the film of vapour, whose light is being examined, be increased, the luminous intensities of all the lines increase, but in different ratios. By virtue of a theorem which will be considered in the next section, the intensity of the bright lines increases more slowly than that of the less visible lines. The impression which a line produces on the eye depends upon its breadth as well as upon its brightness. Hence it may happen that one line being less bright, although broader, than a second, is less visible when the mass of incandescent gas is small, but becomes more distinctly seen than the second line when the thickness of the vapour is increased. Indeed, if the luminosity of the whole spectum be so lowered that only

the most striking of the lines are seen, it may happen that the spectrum appears to be totally changed, when the mass of the vapour is altered. Change of temperature appears to produce an effect similar to this alteration in the mass of the incandescent vapour. If the temperature be raised, no deviation of the maxima of light is observed, but the intensities of the lines increase so differently that those which are most plainly seen at a high temperature are not the most visible at a low temperature. This influence of the mass, and of the temperature of the incandescent gas, explains perfectly why in the spectra of many metals those lines which are the most prominent, when the metal is placed in the gas-flame, are not the most distinct when the spectrum of the induction-spark from the metal is examined. This is most clearly seen in the case of the calcium spectrum. I have found that if a wet string, or a narrow tube filled with water, be placed in the metallic circuit joining the Leyden jar which gives the spark, and if the electrodes be moistened with a solution of chloride of calcium, a spectrum is obtained which coincides precisely with that seen when a chloride of calcium bead is placed in the colourless gas-flame. Those lines appear absent which are the most distinct when an entire metallic circuit is employed. If the narrow column of water be replaced by a column of larger sectional area and of shorter length, a spectrum is produced in which both those lines seen in the flame, and those obtained by the intense spark, are equally plainly visible. In this experiment we see the mode in which the calcium spectrum, as given in the flame, changes into that produced by the bright electric spark.

ON THE REVERSAL OF THE SPECTRA OF COLOURED FLAMES.

In the course of the experiments already alluded to, which Foucault[1] instituted on the spectrum of the electric arc formed between the carbon points, this physicist observed that the bright sodium lines present were changed into dark bands in the spectrum produced by the light from one of the carbon poles, which had been allowed to pass through the luminous arc; and when he passed direct sunlight through the arc he noticed that the double *D* line was seen with an unusual degree of distinctness. No attempt was made to explain or to increase these observations either by Foucault or by any other physicist, and they remained unnoticed by the greatest number of experimentalists. They were unknown to me when Bunsen and I, in the year 1859, commenced our investigations on the spectra of coloured flames.

In order to test in the most direct manner possible the truth of the frequently asserted fact of the coincidence of the sodium lines with the lines *D*, I obtained a tolerably bright solar spectrum, and brought a flame coloured by sodium vapour in front of the slit. I then saw the dark lines *D* change into bright ones. The flame of a Bunsen's lamp threw the bright sodium lines upon the solar spectrum with unexpected brilliancy. In order to find out the extent to which the intensity of the solar spectrum could be increased, without impairing the distinctness of the sodium lines, I allowed the full sunlight to shine through the sodium flame upon the slit, and, to my astonishment, I saw that the dark lines *D* appeared with an extraordinary degree of clearness. I then exchanged the sunlight for the Drummond's or oxyhydrogen lime-light, which, like that of all incandescent

[1] *L'Institut*, 1849, p. 45.

solid or liquid bodies, gives a spectrum containing no dark lines. When this light was allowed to fall through a suitable flame coloured by common salt, dark lines were seen in the spectrum in the position of the sodium lines. The same phenomenon was observed if instead of the incandescent lime a platinum wire was used, which being heated in a flame was brought to a temperature near to its melting point by passing an electric current through it.

The phenomenon in question is easily explained upon the supposition that the sodium flame absorbs rays of the same degree of refrangibility as those it emits, whilst it is perfectly transparent for all other rays. This supposition is rendered probable by the fact, which has long been known, that certain gases, as for instance, nitrous acid and iodine vapour, possess at low temperatures the property of such a selective absorption. The following considerations shew that this is the true explanation of the phenomenon. If a sodium flame be held before an incandescent platinum wire whose spectrum is being examined, the brightness of the light in the neighbourhood of the sodium lines would, according to the above supposition, *not* be altered; in the position of the sodium lines themselves, however, the brightness *is* altered, for two reasons; in the first place, the intensity of light emitted by the platinum wire is reduced to a certain fraction of its original amount by absorption in the flame, and secondly, the light of the flame itself is added to that from the wire. It is plain that if the platinum wire emits a sufficient amount of light, the loss of light occasioned by absorption in the flame must be greater than the gain of light from the luminosity of the flame; the sodium lines must then appear darker than the surrounding parts, and by contrast with the neighbouring parts they may seem to be quite black, although their degree of luminosity is necessarily greater than that which the sodium flame alone would have produced.

The absorptive power of sodium vapour[1] becomes most apparent

[1] By using this expression I do not intend to restrict the meaning to the vapour of metallic sodium, but I would thereby include the vapour of any sodium compound.

when its luminosity is smallest, or when its temperature is lowest. In fact we were unable to produce the dark sodium lines in the spectrum of a Drummond's light, or in that of an incandescent wire, by means of a Bunsen's gas-flame in which common salt was placed; but the experiment succeeded with a flame of aqueous alcohol containing common salt. The following experiment proposed by Crookes[1] likewise very clearly shews this influence of temperature. If a piece of sodium is burnt in a room, and the air thus filled with the vapour of sodium compounds, every flame is seen to burn with the characteristic yellow light. If a small flame in which a bead of soda salt is placed be now fixed in front of a large one, so that the former is seen projected on the latter as a background, the small flame appears to be surrounded with a black smoky mantle. This dark mantle is produced by the absorptive action of the sodium vapours in the outer part of the flame, which are cooler than those in the flame itself. Bunsen and I have produced the dark lines in the spectrum of a common candle-flame, by allowing the rays to pass through a test-tube containing a small quantity of sodium-amalgam, which we heated to boiling; so that the sodium vapour effecting the absorption had in this case possessed a temperature far below the red-heat. The same phenomenon is observed in a much more striking manner if a glass tube is used containing some small pieces of sodium first filled with hydrogen, and then rendered vacuous and sealed. The lower end of the tube can be heated so as to vaporize the sodium. By means of this arrangement, which was proposed by Roscoe, the heated vapour of the sodium, when viewed by the sodium-light, is seen as a dark black smoke which throws a deep shadow, but is perfectly invisible when observed by the ordinary gas-light.

I may here mention an analogous phenomenon which I have observed with the large spectrum apparatus. The spectrum of a moderately bright sodium flame is seen in this instrument to consist of two bright lines, which appear sharply defined, and not broader than corresponds to the

[1] *Philosophical Magazine.* Series IV. Vol. XXI. p. 55.

breadth of the slit. If, however, the flame employed is as bright as that produced by a bead of salt placed in a Bunsen's lamp, the sodium lines appear as two broad ill-defined bands, in the middle of each of which a fine black line is seen, occupying the exact position of the bright line produced by the weaker flame. These black lines are formed by the absorption which a portion of the rays, emitted by the hotter portion of sodium vapour, suffer in passing through the cooler sodium vapours surrounding the flame, and rendered visible in Crookes's experiment.

The sodium flame is characterized beyond that of any other coloured flame by the intensity of the lines in its spectrum. Next to it in this respect comes the lithium flame. It is just as easy to reverse the red lithium line, that is, to turn the bright line into a dark one, as it is to reverse the sodium line. If direct sunlight be allowed to pass through a lithium flame, the spectrum exhibits in the place of the red lithium band a black line which in distinctness bears comparison with the most remarkable of Fraunhofer's lines, and disappears when the flame is withdrawn. It is not so easy to obtain the reversal of the spectra of the other metals; nevertheless Bunsen and I have succeeded in reversing the brightest lines of potassium, strontium, calcium, and barium, by exploding mixtures of the chlorates of these metals and milk-sugar in front of the slit of our apparatus whilst the direct solar rays fell on the instrument[1].

These facts would appear to justify the supposition that each incandescent gas diminishes by absorption the intensity of those rays only which possess degrees of refrangibility equal to those of the rays which it emits; or, in other words, that the spectrum of every incandescent gas must be reversed, when it is penetrated by the rays of a source of light of sufficient intensity giving a continuous spectrum.

[1] The spectra of intermittent electric sparks, such as I have employed in this investigation for the purpose of obtaining the lines of many metals, cannot be reversed by sunlight passing through them, because the duration of each spark is very small in comparison to the length of time which elapses between two consecutive sparks.

We learn how far this supposition is correct, by help of a theorem which I have enunciated, and believe to be of great importance. The theorem considers rays of heat in general; not merely those rays of heat which produce an impression on the eye, and which we therefore call rays of light. It affirms that for each sort of ray the relation between the power of emission and the power of absorption is, at the same temperature, constant for all bodies[1]. In this theorem, however, I suppose that the bodies only emit rays in consequence of the temperature to which they are heated, and that all the rays which are absorbed are transformed to heat; thus the phenomena of phosphorescent bodies are excluded from consideration. From this theorem it follows that an incandescent gas in whose spectrum certain colours are wanting, which are present in the spectrum of another body, is perfectly transparent for such colours; and that such a gas is, therefore, only able to exert an absorption upon the rays occurring in its spectrum, an absorption which increases according to the degree of brightness of this colour in its spectrum. We see also that the supposition to which the observations lead is true as long as the theorem itself is true, that is, as long as the gas emits rays only by virtue of its temperature, and exerts no absorptive action except such a one as causes heat to be liberated.

Another consequence of this theorem, to which I shall presently revert, may here be noticed. If the source of light giving a continuous spectrum, by means of which the spectrum of a glowing gas is to be reversed, be an incandescent body, its temperature must be higher than that of the glowing gas.

[1] For the more precise definition of the terms occurring in this theorem, for its proof, and the conclusions which may be drawn therefrom, see *Philosophical Magazine*, Vol. xx. p. 1, and Poggendorff's *Annalen*, Bd. 109, p. 275.

ON THE CHEMICAL CONSTITUTION OF THE SOLAR ATMOSPHERE.

Fraunhofer was the first to observe that the two dark lines in the solar spectrum, which he named D, coincide with the bright lines which are now known to be the sodium lines. Brewster noticed the presence of some bright lines in the flame of a mixture of carbon or sulphur with saltpetre, which coincided with other dark lines in the solar spectrum. A glance at Plates I. and II. shows the existence of a large number of such coincidences[1].

It is especially remarkable that, coincident with the positions of all the bright iron lines which I have observed, well-defined dark lines occur in the solar spectrum. By the help of the very delicate method of observation which I have employed, I believe that each coincidence observed by me between an iron line and a line in the solar spectrum, may be considered to be at least as well established as the coincidence of the sodium lines and the lines D was up to the present time. The means of observation remaining the same, the degree of certainty with which the coincidence of a bright line with a dark solar line can be established, depends upon the distinctness of each line. I will suppose that, in the case of the iron lines, two lines were considered to be coincident when the distance between them appeared less than that corresponding to half a millimetre on the scale. In my drawing of the solar spectrum the average distance between two adjacent lines is about 2 millimetres; if these lines were equally distant the probability is one half, that a bright line, which in reality had no connexion with them, should appear to coincide with one of them. The same thing holds

[1] These coincidences are not represented in the drawings with absolute exactitude owing to the slight errors produced by printing. To render the determination of the coincidents easy I have noted in the Table of the Supplement all the coincident lines which I have observed.

good if the lines are irregularly distributed, but so that the distance between any two of them is not less than 1 millimetre. In fact, however, much smaller differences in the distance occur, so that the probability of a coincidence becomes less than one half. In this estimation we have considered all the lines which are represented in the drawing, even the least distinct. If, however, we omit these, and only take into consideration lines having the distinctness of those which are represented as being coincident with iron lines, we find the probability that one iron line should appear to coincide with one of these dark lines is considerably less than one half. But in the portion of the spectrum represented in Plates I. and II. about 60 bright iron lines appeared to me to coincide with as many dark solar lines; the probability that this coincidence is a mere work of chance is, therefore, considerably less than $(\frac{1}{2})^{60}$, and therefore less than

$$\frac{1}{1000,000,000,000,000,000}.$$

This probability is rendered still smaller by the fact that the brighter a given iron line is seen to be, the darker, as a rule, does the corresponding solar line appear. Hence this coincidence must be produced by some cause, and a cause can be assigned which affords a perfect explanation of the phenomenon.

The observed phenomenon may be explained by the supposition, that the rays of light which form the solar spectrum have passed through the vapour of iron, and have thus suffered the absorption which the vapour of iron must exert. As this is the only assignable cause of this coincidence, the supposition appears to be a necessary one. These iron vapours might be contained either in the atmosphere of the sun or in that of the earth. But it is not easy to understand how our atmosphere can contain such a quantity of iron vapour as would produce the very distinct absorption-lines which we see in the solar spectrum, and this supposition is rendered still less probable by the fact that these lines do not appreciably alter when the sun approaches the horizon. It does not, on the other hand, seem at all unlikely, owing to the high temperature which we must

suppose the sun's atmosphere to possess, that such vapours should be present in it. Hence the observations of the solar spectrum appear to me to prove the presence of iron vapour in the solar atmosphere with as great a degree of certainty as we can attain in any question of natural science.

As soon as the presence of *one* terrestrial element in the solar atmosphere was thus determined, and thereby the existence of a large number of Fraunhofer's lines explained, it seemed reasonable to suppose that other terrestrial bodies occur there, and that by exerting their absorptive power, they may cause the production of other Fraunhofer's lines. For it is very probable that elementary bodies which occur in large quantities on the earth, and are likewise distinguished by special bright lines in their spectra, will, like iron, be visible in the solar atmosphere. This is found to be the case with calcium, magnesium, and sodium. The number of the bright lines in the spectrum of each of these metals is, indeed, small, but those lines, as well as the dark ones in the solar spectrum with which they coincide, are so uncommonly distinct that the coincidence can be observed with very great accuracy. In addition to this, the circumstance that these lines occur in groups, renders the observation of the coincidence of these spectra more exact than is the case with those composed of single lines. The lines produced by chromium also form a very characteristic group, which likewise coincides with a remarkable group of Fraunhofer's lines; hence I believe that I am justified in affirming the presence of chromium in the solar atmosphere. It appeared of great interest to determine whether the solar atmosphere contains nickel and cobalt, elements which invariably accompany iron in meteoric masses. The spectra of these metals, like that of iron, are distinguished by the large number of their lines. But the lines of nickel, and still more those of cobalt, are much less bright than the iron lines, and I was, therefore, unable to observe their position with the same degree of accuracy with which I determined the position of the iron lines. All the brighter lines of nickel appear to coincide with dark solar lines; the same was observed with respect to some of the cobalt lines, but was not seen to

be the case with other equally bright lines of this metal. From my observations I consider that I am entitled to conclude that nickel is visible in the solar atmosphere; I do not, however, yet express an opinion as to the presence of cobalt.

Barium, copper, and zinc appear to be present in the solar atmosphere, but only in small quantities; the brightest of the lines of these metals correspond to distinct lines in the solar spectrum, but the weaker lines are not noticeable. The remaining metals which I have examined, viz. gold, silver, mercury, aluminum, cadmium, tin, lead, antimony, arsenic, strontium, and lithium, are, according to my observations, not visible in the solar atmosphere.

Through the kindness of M. Grandeau of Paris, I obtained several pieces of fused silicium, and I was thus enabled, by using them as electrodes, to examine the spectrum of this element. The lines in the silicium spectrum are, however, with the exception of two broad green bands at 1810 and 1830, so deficient in luminosity that I was unable to determine their position with sufficient accuracy to reproduce them in my drawing. The two bright green bands do not correspond to dark bands in the solar spectrum, so that, as far as I have been able to determine, silicium is not visible in the solar atmosphere.

According to the theory which has just been explained, a portion of the dark lines of the solar spectrum is caused by absorption in the solar atmosphere. The idea that such is the case was long since proposed and discussed. An objection against this theory, which I cannot pass over in silence, was raised in the year 1847 by A. Matthiessen[1], and lately repeated by Brewster and Gladstone[2]. If the view in question were correct, argue the above physicists, the dark lines produced by absorption in the solar atmosphere must appear darker when the rays from which the spectrum is formed are emitted from the edge of the sun's disc than when they are taken from the central portions, because in the first case they will have to pass through a thicker column of the solar

[1] *Comptes Rendus de l'Academie*, Tom. xxv. p. 548. Poggendorff's *Annalen*, Bd. 73, p. 448.

[2] *Philosophical Transactions*, 1860, p. 158.

atmosphere than in the second case; but by their own observations, as well as those of Professor Forbes, such a difference is not noticed.

These observations were certainly not controlled by any photometric measurements, and we are therefore unable to conclude from them that a difference of this kind does not occur, but simply that it was not striking, that it was much less than the difference observed in certain lines which appear in the spectrum when the sun approaches the horizon, and when the density of *our* atmosphere, through which the rays have to pass, becomes much greater. In fact we cannot expect that the lines caused by absorption in the sun's atmosphere should increase in depth of shade when the starting point of the rays changes from the middle of the disc to the limb, in the same degree as the lines caused by absorption in our atmosphere increase as the sun proceeds from the zenith towards the horizon. The height of the terrestrial atmosphere is a very small fraction of the Earth's radius, and therefore the distance which a ray of light has to pass through our atmosphere, from a point in the horizon, is incomparably greater than the distance which it has to pass when coming from the zenith. The height of the solar atmosphere, judging from the phenomena observed in a total eclipse of the sun, is not small in comparison to the radius of that body; and hence the distances which two rays have to pass, one of which proceeds from the centre and the other from the edge of the sun's disc, do not greatly differ. In addition to this, we must remember that the lowest layers of our terrestrial atmosphere, or those in which the distance traversed by a ray increases most rapidly when it approaches more nearly to the horizon, are those which by virtue of their density must exert the most powerful absorptive action. In the solar atmosphere, on the contrary, it is those layers which are elevated to a certain position above the solid crust of the sun, which act most energetically in producing the dark lines; for the lower layers, which possess a temperature but slightly different from that of the mass, effect but little alteration on the light, as the loss of intensity which each ray suffers on passing through is replaced by the luminosity of the gas itself. The laws, according to which the temperature and

density of the solar atmosphere diminishes with increase of height, regulate the position of the layer which acts most energetically in forming the dark lines in the solar spectrum. There is no reason to suppose that this layer is situated very near to the surface of the sun's solid crust.

These remarks are not intended to convey the impression that the increased depth of shade of the lines in the spectrum, caused by absorption in the solar atmosphere, as expected by Matthiessen, Brewster, and Gladstone, does not occur: they tend simply to show that the fact of no such increase being visible in any line is not opposed to the supposition that a large portion of these lines is caused by absorption in the solar atmosphere; a supposition which necessitates the consideration of other important questions.

ON THE PHYSICAL CONSTITUTION OF THE SUN.

In order to explain the occurrence of the dark lines in the solar spectrum, we must assume that the solar atmosphere incloses a luminous nucleus, producing a continuous spectrum, the brightness of which exceeds a certain limit. The most probable supposition which can be made respecting the Sun's constitution is, that it consists of a solid or liquid nucleus, heated to a temperature of the brightest whiteness, surrounded by an atmosphere of somewhat lower temperature. This supposition is in accordance with Laplace's celebrated nebular-theory respecting the formation of our planetary system. If the matter, now concentrated in the several heavenly bodies, existed in former times as an extended and continuous mass of vapour, by the contraction of which sun, planets, and moons, have been formed, all these bodies must necessarily possess mainly the same constitution. Geology teaches us that the Earth once existed in a state of fusion; and we are compelled to admit that the same state of things has occurred in the other members of our solar system. The amount of cooling which the various heavenly bodies have undergone, in accordance with the laws of radiation of heat, differs

greatly, owing mainly to difference in their masses. Thus whilst the moon has become cooler than the Earth, the temperature of the surface of the Sun has not yet sunk below a white heat. Our terrestrial atmosphere in which now so few elements are found, must have possessed, when the Earth was in a state of fusion, a much more complicated composition, as it then contained all those substances which are volatile at a white heat. The solar atmosphere at this present time possesses a similar constitution.

The idea that the Sun is an incandescent body is so old, that we find it spoken of by the Greek philosophers. When the solar spots were first discovered, Galileo described them as being clouds floating in the gaseous atmosphere of the Sun, appearing to us as dark spots on the bright body of the luminary. He says, that if the Earth were a self-luminous body, and viewed from a distance, it would present the same phenomena as we see in the Sun. "According as such or such a region should happen to be behind a cloud, we should perceive spots sometimes in one part of the apparent disc, sometimes in a different part; the greater or less opacity of the cloud would occasion a greater or less diminution in the terrestrial light. At certain epochs there would be few spots; afterwards many would be visible; here they would extend, there they would contract: these spots would share in the rotatory motion of the Earth, supposing that our globe was not fixed, and, as their depth would be very inconsiderable compared with their breadth, as soon as they approached the limb their diameters would sensibly diminish[1]".

This theory of the constitution of the Sun-spots has been relinquished by many astronomers, on account of some peculiarities in the spots which further observations have brought to light. Arago[2], in explaining the physical condition of the Sun, according to the theory which he considers as the one almost universally adopted, assumes that the Sun consists of a dark nucleus, which is in the first place surrounded by an opaque and

[1] Arago's *Popular Astronomy*, translated by Smyth and Grant, Vol. I. p. 445.

[2] *Ibid.* Vol. I. p. 411.

reflecting atmosphere, and that this is inclosed by a luminous atmosphere or photosphere, which in its turn again is surrounded by a transparent atmosphere. The same Astronomer seems to think that the surface of the Sun may possess a temperature somewhat similar to that of our Earth, for he says[1], "If I were asked whether the Sun can be inhabited by beings organised in a manner analogous to those which people our globe, I should not hesitate to reply in the affirmative. The existence of a central obscure nucleus, enveloped in an opaque atmosphere, far beyond which the luminous atmosphere exists, is by no means opposed, in effect, to such a conception."

It is to Wilson's observations that we owe the proposal of this very strange constitution of the sun. He noticed that when a spot moves across from the centre of the sun's disc towards its western limb, the penumbra contracts more quickly on the side nearest the centre of the disc, than it is seen to do on the opposite side. The centre of the spot is supposed to be a portion of the dark surface of the sun, seen through two overlying openings, one formed in the photosphere, and the other in the lower reflecting atmosphere; the penumbra is supposed to be a portion of this opaque atmosphere, the opening in it being smaller than that in the photosphere.

The hypothesis concerning the constitution of the sun which has been thus put forward in order to explain the phenomena of the sun-spots, appears to me to stand in such direct opposition to certain well established physical laws, that in my opinion it is not tenable even supposing that we were unable to give any other explanation of the formation of the sun-spots. This supposed photosphere must, if it exists, radiate heat towards the sun's body as well as from it. Every particle of the upper layer of the lower or opaque atmosphere will, therefore, be heated to a temperature at least as high as that to which it would be raised if placed on the earth in the focus of a circular mirror exposed to the sun's rays, whose surface seen from the focus is larger than a hemisphere. The less transparent the atmosphere is, the quicker will this

[1] Arago's *Astronomy*, Vol. I. p. 469.

temperature be attained, and the smaller will be the distance to which the direct radiation of the photosphere will penetrate into the mass of the atmosphere. What degree soever of opacity the atmosphere may possess, it is certain that in time the heat will be transmitted, partly by radiation, partly by conduction and convection, throughout the whole mass; and if the atmosphere ever had been cold, it is clear that in the course of ages it must have become intensely heated. This atmosphere must act on the nucleus in the same way as the photosphere acts upon it; the nucleus must likewise become heated to the point of incandescence. It must, therefore, give off light and heat; for all bodies begin to glow at the same temperature. Draper has ascertained experimentally the truth of this law for solid bodies, and I have given a theoretical proof for all bodies which are not perfectly transparent; this, indeed, follows immediately from the theorem, concerning the relation between the power of absorption and the power of emission of all bodies.

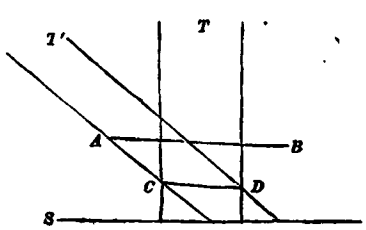
But even the phenomena exhibited by the solar spots, for whose benefit the hypothesis of a dark solar nucleus was started, may, I believe, be explained more completely and more naturally by help of the supposition concerning the constitution of the sun, which the consideration of the solar spectrum has led me to adopt.

In the atmosphere of the sun phenomena must occur similar to those which we find take place in our own; local diminution of temperature must, there as here, give rise to the formation of clouds; only that the solar clouds will be of a different chemical composition from terrestrial ones. When a solar cloud is formed, all the portions of atmosphere lying above it will be cooled down, because a portion of the rays of heat which are emitted from the incandescent surface of the sun are cut off by the cloud. This cooling effect will be the more considerable the thicker and larger the cloud is, and will be felt more in the neighbourhood of the cloud than at points further removed. The result of this is, that the upper portions of the cloud must increase with accelerating velocity and become cooler. The temperature of the cloud sinks below the point of incandescence, it becomes opaque, and

forms the dark nucleus of a solar spot. A diminution of temperature must also occur at a considerable elevation above this cloud, and if, in this position, the vapours be cooled to a temperature not far removed from their points of condensation, either owing to the prevailing low temperature or to the contact of two currents of air, this diminution of temperature must cause the production of a second cloud. This will be more transparent than the first, because the density of the vapour present at high is less than that at low elevations; and this second cloud, when it has attained sufficient dimensions, will appear as a semi-opaque penumbra. In our own atmosphere we frequently see clouds formed simultaneously at different elevations, the dense ones near the earth, light ones at a greater height. It may frequently happen that such a simultaneous formation of cloud at different heights occurs on the earth where it cannot be observed; but even supposing that this does not take place as a rule on the earth, there is no reason why it should not regularly occur on the sun; for there the atmosphere receives its heat solely from below, whilst with us it also receives it from above, namely from the solar rays.

These two layers of clouds play the same part in the view which I take, as the two openings in the opaque atmosphere, and in the photosphere, in the theory to which I object. If the two clouds be supposed to be of the same dimensions, and in the same positions as the two openings, Wilson's observation can be explained with equal ease according to both theories[1].

[1] The truth of this assertion is proved by the following figure, in which AB and CD represent the two clouds in the one theory, and the two openings in the other. S represents the surface of the Sun, which according to one theory is supposed to be luminous, and according to the other, dark. If the Earth be in the direction T, the solar spot appears in the middle of the Sun's disc and the penumbra equally on both sides. If the Earth is in the direction T', the spot is seen near the limb of the Sun, and the penumbra has vanished at C, or at the side nearest to the Sun's centre. A difference between the phenomena as supposed by the two



According to the statements of various observers, Wilson's phenomenon is by no means general; according to the usual theory the exceptions can only be explained by a change in the structure of the spot, whilst according to the view which I adopt, they may be accounted for by the distance between the two clouds being but small.

In the descriptions of the sun-spots, importance is attached to the fact, that the dark portion appears to possess a well defined edge, and that the edge of the penumbra nearest the spot appears brighter than the outside edge. This I imagine may be explained by the upper cloud being very thin in the middle, and thickest round the edges. The cooling effect produced above the cloud by a portion of the direct rays from the solar body being thus cut off gives rise to a downward current of air. The air which is carried from the higher regions of the atmosphere must be replaced, and hence an upward current is developed round the cloud. These two currents will meet in the cloud itself, and there give rise to horizontal currents proceeding from the centre towards the edge of the cloud. As the differences in temperature which produce these winds may amount to thousands of degrees, the force of the currents must far exceed that of the most violent terrestrial tornadoes; so that the masses of vapours will be easily carried along, and the cloud will become thinner at the centre and thicker at the edges. If we examine the careful drawings of the solar spots published in the sixth volume of Schumacher's *Astronomische Nachrichten*[1], we notice that in most of the penumbras dark bands are represented, which become broader as we proceed from the interior to the exterior of the mass. These bands appear to me to indicate the presence of the currents, as the parallel bands of clouds at great

theories is as follows: when the Earth passes in the direction TT' to a position beyond T', according to one theory, a portion of the nucleus of the spot must appear beyond the penumbra, whilst, according to the other theory, a portion must be covered by the penumbra. It seems to be difficult to decide which of these phenomena is in reality observed, owing to the alterations which the spots undergo, and the indistinctness with which they are seen when situated near the edge of the Sun's disc.

[1] Arago's *Astronomy*, Vol. I. Plates IX, X, XI.

heights in our own atmosphere point out the direction of the winds prevailing at such elevations. The violence of the storms occurring in the neighbourhood of the clouds explains the great rapidity with which the spots undergo alteration.

One of the most remarkable peculiarities which the spots present, is, that they are observed only within a certain distance of the Sun's equator. This cannot be directly explained according to the theory which I propose, but we may be more easily made to understand how this might occur according to my view than if the other theory were held. Secchi has concluded from his own observations that the polar regions of the Sun possess a lower temperature than the equatorial zones. If this be the case, the atmosphere must move, on the Sun's surface, from the poles towards the equator, where it must rise and return in the higher regions of the air from the equator to the poles; it must, in fact, partake of the motion which we observe in our own atmosphere consequent upon the great heat of the tropics. This motion will be more regular in the solar atmosphere than in our own, owing to absence of the disturbances caused by the variation of day and night, and summer and winter. There as well as here, at a certain distance from the equator, the equatorial current must sink, and meet the opposite polar current. These currents in the solar atmosphere must give rise to the formation of clouds. If we consider these as the chief cause of the formation of cloud, we easily understand that it is only within a certain distance of the equator that clouds are formed of a density and size sufficient to enable us on the earth to observe them as sun-spots.

The faculæ and luculi are seen when the portion of the Sun's body under observation possesses a larger power of emission, or a higher temperature than the neighbouring parts. The fact that the faculæ and the spots often occur close together, is not extraordinary; the faculæ may give rise to the formation of clouds in their neighbourhood, by the inequalities of temperature and the consequent mixing of currents of air of different composition. It is, on the other hand, quite possible

that clouds may aid the formation of the faculæ, as they may act as reflectors and lessen the radiation from the underlying portion of the solar body, and thus the continual supply of heat from within may give rise to a considerable elevation of temperature.

Arago has made an observation which he considers as an important confirmation of the view he supports, and I cannot leave this without comment. At the above-mentioned part of his work[1] Arago says, "It was desirable, in order to impress the theory which I have just explained with the seal of certainty, that we should succeed in determining, by direct observations, the nature of the incandescent substance of the Sun. This object I have attained, I think, by the aid of the phenomena of polarization."...And further on, he remarks[2] "I have found that the light which emanates, under an angle sufficiently small from the surface of a solid body, or of a liquid incandescent body, even when the surface is not completely polished, offers evident traces of polarization." According to Arago a glowing gas is the only source from which light proceeds perfectly unpolarized. He observed that the light which reaches us from points on the sun's disc near the edge, does not shew the slightest trace of polarization; and hence he concludes "that the luminous matter which forms the apparent edge of the solar disc is gaseous."

The statement that incandescent gas is the only source of non-polarized light, is, however, incorrect, for Arago himself mentions that the common luminous gas-flame emits perfectly unpolarized light; and the light in this case is almost entirely caused not by glowing gas, but by incandescent particles of solid carbon which are liberated in the flame. An incandescent haze consisting of solid or liquid particles must act in a manner precisely similar to such a flame. From Arago's observations we may, therefore, at most conclude, that the sun-light which reaches our eyes is not emitted from the coherent solid or

[1] Arago's *Astronomy*, Vol. I. p. 413.

[2] Ibid. Vol. I. p. 418.

liquid crust of the sun. These observations may lead us to suppose that, between the coherent body of the sun and the gaseous atmosphere, a layer of white-hot haze exists, which is so dense that the rays from the sun's incandescent body cannot penetrate it. The assumption of such a layer of haze is, it appears to me, unnecessary for the explanation of Arago's observations. Arago noticed that the rays emitted at an acute angle by a glowing solid or liquid body indicated perceptible traces of polarization even when the surface was not perfectly polished. If the mass of the sun is mainly liquid, and its seas are in continual motion as our own are when raised by storms to foaming waves, can we suppose that the light of these seas should be perceptibly polarized in the plane in which it would be polarized if the surface of the luminous fluid were in equilibrium? I believe not: the difference of direction of the surfaces from which the rays coalesce before they reach our eyes will bring the light very nearly to the non-polarized condition. That such motions should occur in the solar oceans seems anything but improbable, when we consider the enormous changes of temperature occurring in the solar atmosphere, and the force of the currents which in consequence must be produced.

HEIDELBERG, *June*, 1861.

88122

SUPPLEMENT.

TABLE

OF THE DARK LINES OF THE SOLAR SPECTRUM, SHOWING THE COINCIDENCES WITH THE BRIGHT LINES OF THE SPECTRA OF MANY METALS, AS GIVEN ON PROFESSOR KIRCHHOFF'S DRAWING.

PLATE I. FIG. 1.

1000.0	1*a*		1103.3	2*b*		1177.6	1*a*		1247.4	3*b*	
1000.4	1*a*		1104.1	2*b*		1178.6	1*a*		1248.6	3*d*	
1001.4	1*a*		1107.1	2*c*		1179.0	1*a*		1250.4	3*c*	
1002.8	6*b*	*Na*	1111.4	1*a*		1179.4	1*a*		1251.1	2*b*	
1005.0	2*b*	*Ni*	1119.0	2*a*		1179.8	1*a*		1253.3	2*b*	
1006.8	6*b*	*Na*	1122.6	2*a*		1180.2	1*a*		1255.2	2*b*	
1011.2	3*a*		1128.3	2*b*		1183.4	2*a*		1257.5	3*c*	
1023.0	1*a*		1130.9	2*b*		1184.8	3*a*		1258.5	2*b*	
1025.5	3*a*		1133.1	3*c*		1186.8	2*a*		1264.4	1*a*	
1027.7	2*a*		1133.9	3*c*		1187.1	2*a*		1264.9	2*a*	
1029.3	3*c*	*Ca, Ni*	1135.1	4*d*		1189.3	3*b*		1267.3	3*a*	
1031.8	2*a*	*Ba*	1135.9	2*c*		1190.1	2*b*		1268.0	3*a*	
1032.8	1*a*		1137.0	2*b*		1193.1	3*a*		1271.9	1*a*	
1035.3	1*a*		1137.8	3*b*		1199.6	2*d*		1272.4	1*a*	
1058.0	2*b*		1141.3	2*c*		1200.6	4*b*	*Fe*	1274.2	3*b*	*Ba*
1063.0	2*b*		1143.6	2*c*		1201.0	2*a*		1274.7	3*a*	*Sr*
1065.0	2*b*		1146.2	1*b*		1203.5	2*c*		1276.2	2*a*	
1066.0	1*a*		1147.2	1*b*		1204.2	2*c*		1276.7	1*a*	
1067.0	2*b*		1148.6	1*b*		1204.9	2*d*		1280.0	6*d*	
1070.5	2*b*		1149.4	1*b*		1206.1	1*c*		1281.3	3*c*	
1073.5	1*a*		1151.1	4*b*		1207.3	5*g*	*Fe*	1282.6	2*c*	
1074.2	1*a*		1152.5	2*b*		1217.8	5*d*	*Fe, Ca*	1285.3	2*c*	
1075.5	3*a*		1154.2	2*b*		1219.2	3*c*	*Ca*	1287.5	1*c*	*Ba*
1077.5	1*a*		1155.7	3*b*		1220.1	2*c*		1289.7	2*c*	
from 1078.9 to 1079.7	1		1155.9	2*c*		1221.6	5*d*	*Ca*	1291.9	3*c*	
			1158.3	2*a*		1224.7	5*d*	*Ca*	1293.8	3*c*	
1080.3	1*a*		1160.9	2*a*		1225.3	1*b*		1294.5	3*c*	
1080.9	1*a*		1165.2	1*a*		1226.6	2*d*		1295.6	1*a*	
1081.8	2*b*	*Cu*	1165.7	1*a*		1228.3	2*d*	*Ca*	1296.3	2*c*	
1083.0	2*a*	*Ba*	1167.0	1*d*		1229.6	4*c*	*Ca*	1297.5	1*a*	
1087.5	2*a*		1168.3	1*a*		1230.5	2		1298.9	5*c*	
1089.6	2*a*		1169.4	1*a*		1231.3	5*d*	*Fe*	1299.7	2*c*	
1096.1	3*c*	*Fe*	1170.6	2*c*		1232.8	2*b*		1302.0	2*c*	
1096.8	1*a*		1174.2	5*d*		1235.0	3*d*	*Ca*	1303.5	5*c*	
1097.8	1*a*		1175.0	2*a*		1237.8	2*c*		1306.7	5*c*	
1100.4	1*a*		1176.6	3*c*		1239.9	4*a*	*Fe*	1315.0	4*c*	
1102.1	3*b*		1177.0	2*a*		1242.6	6*c*	*Fe*	1315.7	2*b*	
1102.9	3*a*		1177.3	1*a*		1245.6	4*d*	*Fe*	1319.0	3*c*	*Co*

PLATE I. FIG. 2.

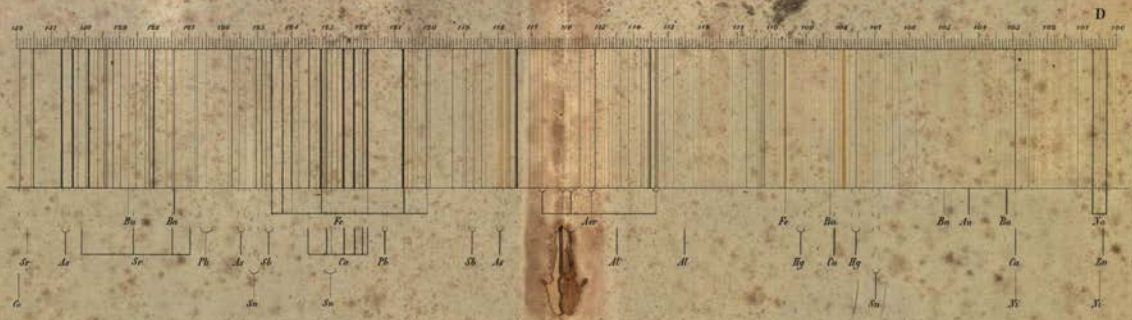
1315.0	4c		1390.9	5d	Fe	1464.8	1a		1543.7	2a	
1315.7	2b		1394.2	4c		1465.3	1a		1545.5	2a	
1319.0	3c	Co	1395.3	1c		1466.8	5c	Fe	1547.2	3a	
1320.6	4c	Sr	1396.4	2c		1468.8	2b		1547.7	2a	
1321.1	3b		1397.5	5c	Fe	1469.6	1b		1551.0	2a	
1323.3	2b		1400.2	3b		1473.9	5b	Fe	1551.6	2a	
1324.0	2b		1401.6	4c	Fe	1475.3	1a		1555.6	2a	
1324.8	4d	Ni	1403.1	3c		1476.8	1a		1557.3	3a	
1325.3	2d		1404.1	1b		1477.5	1a		1561.0	1a	
1327.7	4b		1405.2	3b		1483.0	4b		1564.2	1a	
1328.7	2b		1410.5	4c	Fe	1487.7	5b	Fe	1566.5	2b	Co
1330.4	3b		1412.5	2b		1489.2	2c		1567.5	2b	
1333.3	1a		1414.0	2b		1489.9	1a		1569.6	5c	Fe
1334.0	4b		1415.8	2b		(1491.2	1c		1573.5	5a	
1336.3	1b		1419.4	2b		(1491.6	3c		1575.4	1b	
1337.0	4d	Fe	1421.5	6c	Fe	1492.4	4b		(1577.2	5c	Fe
1337.8	1b		1423.0	5b	Fe	1493.1	4b		(1577.6	3c	
1338.5	1b		1423.5	2b		1494.5	1a		1579.4	2a	
1343.5	6c	Fe	1425.4	5b	Fe	1495.9	1a		1580.1	2a	
1351.1	5d	Fe	1427.5	3b		1497.3	1a	Cu	1588.3	1g	Cu
1352.7	5b	Fe	1428.2	5b	Fe	1501.3	2b		1589.1	3b	
1356.5	1a		1430.1	5b		1504.8	1a		1590.7	3b	
1360.9	1a		1431.2	1b		1505.3	1a		1592.3	3b	
1361.6	1a		1438.9	4c	Co	1505.7	2a		1598.9	2b	
1362.9	5b	Fe	1440.2	1b	Co	1506.3	5c	Fe	(1601.4	6b	Cr
1364.3	1a		1443.1	2b		1508.6	5b	Fe	(1601.7	3d	
1364.7	1a		1443.5	2b	Ca	1510.3	2c	Co	1604.4	5b	Cr
1367.0	6d	Fe	1444.4	4b		1515.5	4d		1606.4	5b	Cr
1371.4	1b	Ba	1446.7	4c		1516.5	4c		1609.2	5b	
1372.1	1b		1448.7	2a	Co	1519.0	4d		1611.3	1c	
1372.6	5b	Fe	1449.4	1a	Co	1522.7	6c	Fe, Ca	1613.9	3b	
1374.8	1c		1450.8	5c	Fe	1523.7	6c	Fe	1615.6	2b	
1375.8	2a		1451.8	5b	Fe	1525.0	1b	Co	1616.6	1b	
1377.4	1a		1453.7	1a		1527.7	5c	Fe, Co	1617.4	2b	
1379.0	1a		1454.7	3b		1528.7	5c	Ca	1618.2	3b	
1380.5	4c	Fe	1456.6	1a		1530.2	4c	Ca	1618.9	4b	
1384.7	4c	Fe	1458.6	3c		1531.2	4c		1621.5	1b	
1385.7	5b	Cr	1461.5	2c		1532.5	4b	Ca	1622.3	5c	Fe
1386.3	2b		1462.2	2c		1533.1	4b	Ca	1623.4	5b	Fe
1387.4	2b		1462.8	5c	Fe	(1541.4	1g		1627.2	5b	Ca
1389.4	6c	Fe	1463.3	5c	Fe	(1541.9	3b		1628.2	1b	

PLATE II. FIG. 1.

1621.5	1*b*		1690.0	5*b*	*Ni*	1785.0	4*b*		1870.6	3*a*	
1622.3	5*c*	*Fe*	1691.0	5*b*		1787.7	2*c*		1872.4	5*b*	
1623.4	5*b*	*Fe*	1693.8	6*e*	*Fe*	1788.7	3*b*		1873.4	6*b*	
1627.2	5*b*	*Ca*	1696.5	3*c*		1793.8	4*b*		1874.2	2*a*	
1628.2	1*b*		1697.0	3*c*	*Ni*	1795.4	1*a*		1874.8	2*a*	
1631.5	1*b*		1701.8	5*c*	*Fe*	1796.0	3*a*		1875.8	2*c*	
1633.5	4*g*		1704.6	2*c*		1797.8	1*a*		1876.5	6*b*	
1634.1	6*g*	*Mg*	1704.9	3*b*		1799.0	4*c*		1884.3	6*b*	
1634.7	4*g*		1707.6	2*c*		1799.6	3*b*		1885.8	6*b*	
1638.7	1*b*		1707.9	3*b*		1806.4	2*b*		1886.4	6*b*	
1642.1	1*b*		1710.7	5*a*		1818.7	5*b*		1889.5	1*g*	
1643.0	1*b*	*Ni*	1712.2	3*b*		1821.4	5*b*		1891.0	3*b*	
1647.3	5*a*		1713.4	5*b*		1822.6	3*a*		1892.5	5*b*	
1648.4	4*e*		1715.2	4*b*		1823.2	2*a*		1893.8	1*b*	
1648.8	6*f*	*Mg*	1717.9	4*b*		1823.6	2*a*		1894.8	3*b*	
1649.2	4*e*		1719.4	1*c*		1828.6	1*b*		1896.2	4*b*	
1650.3	6*b*	*Fe*	1726.9	1*a*		1830.1	3*b*		1897.9	1*c*	
1653.7	6*b*	*Fe, Ni*	1727.3	3*b*	*Ni*	1832.8	2*a*	*Ca*	1900.0	1*c*	
1654.0	4*c*		1733.6	5*b*		1833.4	6*c*		1904.5	4*b*	
1655.6	6*e*	*Fe, Mg*	1734.6	3*b*		1834.3	6*c*		1905.1	2*c*	
1655.9	4*d*		1737.7	5*d*		1835.9	3*b*		1908.5	5*d*	
1657.1	5*b*		1741.0	4*b*	*Cu*	1836.7	3*c*		1911.9	3*c*	
1658.3	2*b*		1742.7	1*a*		1837.5	3*c*		1916.2	1*d*	
to 1659.4	1		1743.1	1*a*		1841.0	4*b*		1917.5	4*b*	
1662.8	5*b*	*Fe*	1744.6	2*a*		1841.6	4*b*		1917.9	4*b*	
1667.4	3*a*		1748.9	3*c*	*Ni*	1842.2	4*b*	*Ni*	1919.8	4*b*	
1670.3	1*a*		1749.6	2*d*	*Ni*	1848.9	2*c*		1920.2	4*b*	*Ni*
1671.5	3*b*		1750.4	5*c*		1851.0	1*c*		1921.1	4*b*	
1672.2	4*a*	*Ni*	1752.0	2*b*		1853.2	3*b*		1922.0	4*b*	
1673.7	4*a*		1752.8	4*c*		1854.0	2*b*		1922.4	4*b*	
1674.7	3*c*	*Cu*	1762.0	3*c*		1854.9	4*c*		1923.5	4*b*	
1676.2	2*d*		1771.5	3*c*		1856.9	1*c*		1925.8	4*b*	*Ni*
1676.5	4*b*		1772.5	3*c*		1857.9	2*b*		1928.0	4*b*	
1677.9	4*c*		1774.0	2*b*		1860.4	2*b*		1931.2	1*c*	
1681.6	4*c*		1775.8	3*b*	*Ni*	1861.3	3*c*		1932.5	1*c*	
1684.0	4*a*	*Ni*	1776.5	3*c*	*Ni*	1862.3	2*b*		1936.2	3*c*	
1684.4	1*b*		1777.5	3*c*		1864.9	3*b*		1939.5	2*c*	
1685.9	2*a*		1778.5	3*c*		1867.1	5*d*	*Fe*			
1686.3	2*a*		1782.7	3*b*		1868.4	5*b*	*Ni*			
1689.5	5*c*		1784.4	1*b*		1869.5	1*c*				

PLATE II. FIG. 2.

1931.2	1c		2019.5	2a		2104.0	4a		2187.1	5a	
1932.5	1c		2021.2	1g		2105.1	4b		2187.9	5a	
1936.2	3c		2024.9	1a		2107.0	1a		2188.5	5a	
1939.5	2c		2025.7	4a	*Ni*	2107.4	2a		2190.1	5b	
1940.6	2c		2026.8	4b		2109.1	2b		(2191.9	3c	
1941.5	3b		2031.1	2c	*Ba*	2111.1	3b		(2192.3	5b	
1943.5	2c		2035.4	1b		2112.7	3b	*Ni*	2193.3	5a	
1944.5	3b		2039.6	1b		2115.0	3a	*Ni*	2195.7	2b	
1947.6	4c		2041.3	6c	*Fe*	2115.4	3a		2197.1	2b	
1949.4	1c		2042.2	6b	*Fe*	2119.8	1b		2197.7	2b	
1953.6	2b		2044.5	5b		2121.2	4b		2198.8	4a	
1960.8	6b		2045.0	5b		2121.9	5c		2199.2	3a	*Ni*
(	4	*Fe*	2047.0	3d		2124.3	1b		2201.1	2b	
1961.2	6b		2047.8	3b		2125.1	2b		2201.9	5c	
1964.3	2c		2049.3	3a		2127.7	3b		2203.3	2a	
1966.2	2b		2049.7	3a		2132.3	2a	*Co*	2203.8	1a	
1966.7	2b		2051.3	3c		2132.7	1a		2205.1	1b	
1970.1	3b		2053.0	4b		2133.8	2a		2206.4	1a	*Co*
1974.7	4b		2053.7	4c		2134.3	1a		2206.7	1a	
1975.7	2d		2058.0	6c	*Fe,Ca*	2136.0	5a	*Zn*	2209.1	4c	
1979.2	3c		2060.0	2b		(2138.0	2g		2211.7	4b	
1982.8	5a		2060.6	2a		(2138.4	4a		2213.4	4b	
1983.3	5a		2061.0	1a		2139.5	4a		2215.1	1b	
1983.8	5a		2064.7	2c	*Ni*	2140.4	4a		2216.7	3b	
1984.5	4b		2066.2	5c	*Fe*	2141.9	2a		2217.5	3b	
1985.8	4b		2067.1	5c	*Fe*	2142.4	5a		2218.3	3a	
1986.9	2a		2067.8	3b		2144.6	4a		2219.8	3b	
1987.5	3a	*Ni*	2068.8	3b		2146.9	3a		2221.3	1a	
1989.5	6c	*Ba*	2070.6	1b		2147.4	4a		2221.7	1a	
1990.4	5b		2071.3	1b	*Co*	2148.5	4a		2222.3	5c	
1991.8	1b		2073.5	3b	*Ni*	2148.9	3a		2223.5	3c	
1994.1	5b		2074.6	2b		2150.1	3a		2225.4	2b	
1996.9	2a		2076.5	1b		2150.5	3a		2226.2	4b	
1997.5	2a		2077.3	2b		2157.0	3a	*Co,Au*	2227.6	2a	
1999.6	2c		(2079.5	4e		2157.4	5a		2228.6	2a	
2000.6	5a		(2080.0	6g		2159.0	1c		2229.1	4a	
2001.6	5c	*Fe*	(2080.5	4e		2160.6	5a		2230.7	4a	
2003.2	3b		2082.0	6a	*Fe*	2160.9	4a		2231.2	2a	
2003.7	1a		2084.6	2b		2161.7	4a		2232.3	4a	
(2004.9	2d		2086.0 to 86.9	1		2162.6	3a		(2233.7	5c	
(2005.2	6d	*Fe*	2086.9	3b	*Ni*	2163.7	4a		(2234.0	2c	
2007.2	6c	*Fe*	2087.6	1a		2164.0	4a	*Ni*	2237.4	1b	
2008.1	1b	*Ni*	2089.7	1a		2167.5	6b		2238.7	1b	
2008.6	1b		2090.9	1a		2171.5	3b	*Co*	2240.0	3b	*Zn*
2009.8	2b		2094.0	2b		2172.2	2a		2241.4	2b	
2013.9	2a		2096.8	1b		2175.7	2b		2245.1	3b	
2014.3			2098.8	1a		2176.4	1b		2246.2	1b	
2015.7 to 16.9	1c		2099.8	2a		2179.9	5b		2248.2	3c	
(2017.7	2b		2100.4	1a		2181.2	3e		(2249.7	6a	*Ni*
(	1		2102.6	4a		2184.9	5b		(2250.0	3d	
2018.5	2b		2103.3	4b		2186.5	3b				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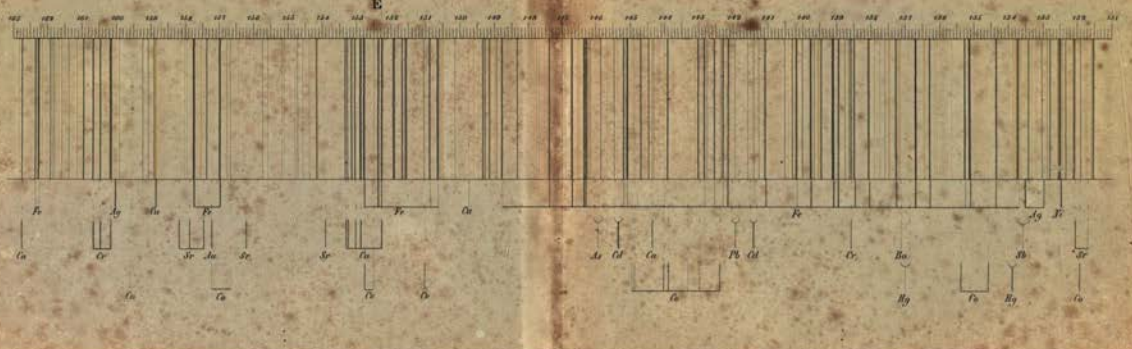
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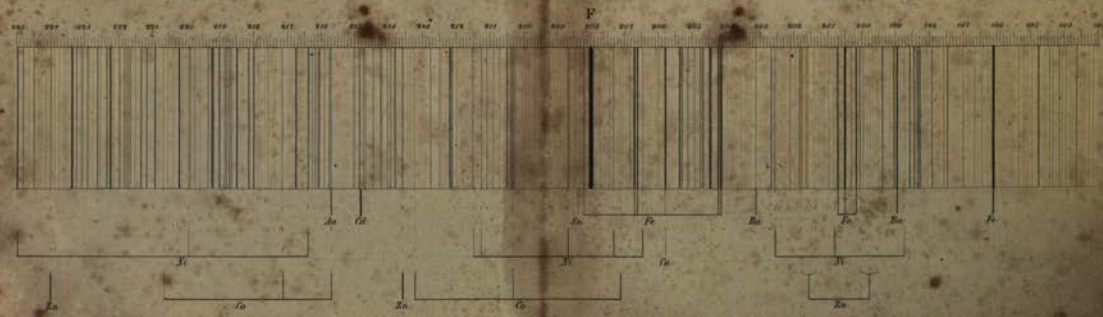
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Fig. 2.

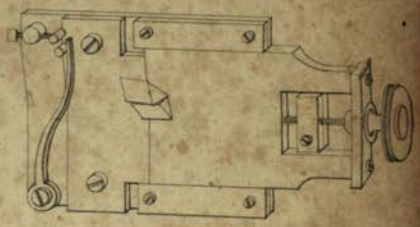
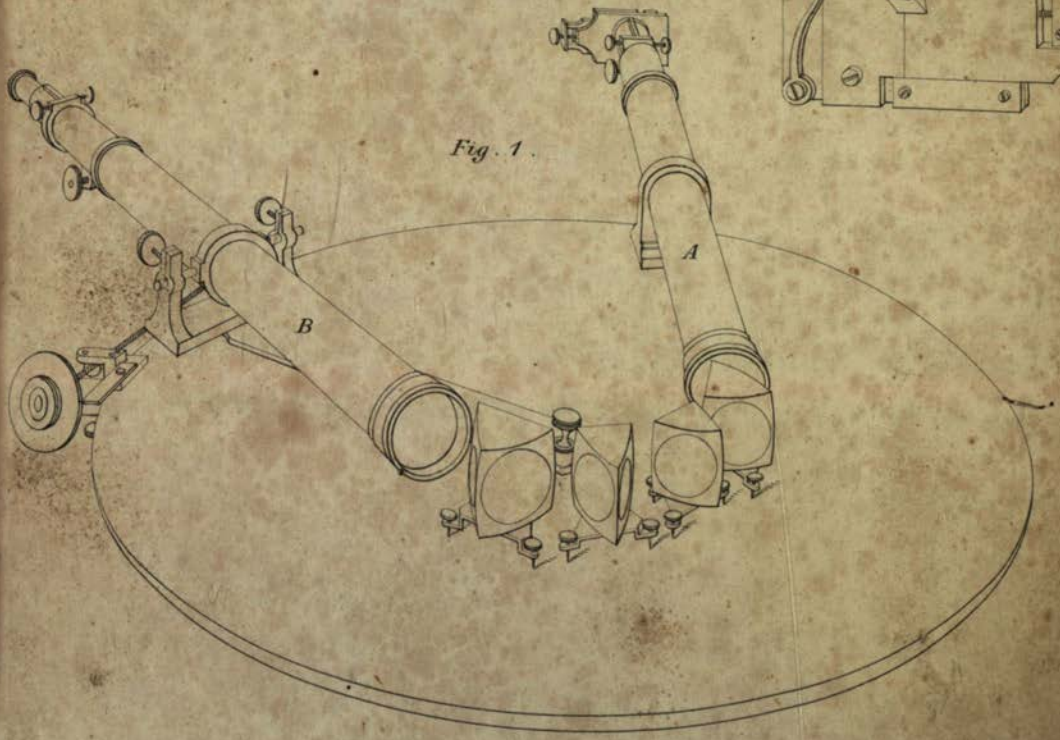


Fig. 1.



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